Original Research Article

Association of different satellite driven products with Evapotranspiration in Tamil Nadu, India (2010-2020)

Abstract

Evapotranspiration is an important phenomenon of hydrological cycle mainly influenced by meteorological factors and other vegetation characteristics. In this study, the relationship between Actual Evapotranspiration (AET) with Normalized Difference Vegetation Index (NDVI) and Land Surface Temperature (LST) were analysed using Moderate Resolution Imaging Spectroradiometer (MODIS) TERRA satellite data products with the help of Geographic Information System (GIS) software. The duration of study was during South West Monsoon (SWM) season from June to September, over a period of ten years (2011 to 2020) for all seven Agro Climatic Zones (ACZ) of Tamil Nadu, India. The results showed that moderate to strong positive correlation were observed between AET and NDVI (r= 0.3 to 0.9) in all seven ACZ. The AET and LST showed a weak to strong negative correlation (r= -0.4 to -0.7) in six ACZs except High Rainfall Zone (HRZ) which might be due to lower LST and high NDVI values recorded in the HRZ which exhibited a weak positive relationship (r=0.2). Relationship between AET, LST and NDVI are highly useful for parametrizing evapotranspiration in different climatic conditions, analyzing different crop growth and production and helps in planning water management strategies at regional scale.

Keywords: *Actual Evapotranspiration, Land Surface Temperature, NDVI, MODIS*

1. Introduction

Evapotranspiration (ET) is the main mechanism regulating energy and water transfers among the hydrosphere, atmosphere, and biosphere [1]. ET has a close relationship to both the mass balance and the energy balance of terrestrial ecosystems, it is one of the most significant land surface processes [2]. Conventional methods of ET estimation measures point specific values which are not representative of spatial distribution of ET. Satellite based remote sensing is promising tool which is extensively used to evaluate the spatial distribution of ET at regional scale [3, 4].

Remote sensing technique can estimate actual ET at regional as well as local spatial scale with less cost and less time [5]. NDVI is generally used as vegetation index (VI) for calculating the crop coefficient (Kc) based on the spectral reflectance of vegetation in near and infra-red region. Actual ET estimated by using satellite based Kc values gives more accurate values than the tabulated Kc values because it considers real time vegetation cover and spatial variability in fields [6]. Crop coefficient based on remote sensing is highly useful for developing regional and local actual ET maps [7].

Natural vegetation is among the most important features that regulates the variation in LST distribution over the region [4]. In bare soil condition LST indicates the surface temperature of soil whereas in case of densely vegetated condition it refers to the vegetation canopy temperature [8]. Land surface temperature (LST) considered as one of the important sources of input data for modelling land surface processes, such as actual and potential evapotranspiration (ET), which is a crucial part of many agricultural and ecological research [9]. Due to complexity of the parameterization of the models, it is still difficult to identify the uncertainties initiating from the various input variables in the calculation of ET [10].

In previous studies, correlation of actual ET with NDVI and actual ET with LST was studied which showed high spatial and temporal variation of actual ET for different climatic condition [11]. Hence, there is need to study the relationships between actual ET, LST and NDVI in different climatic zones for better understanding and application of the relationships for the further analysis such as ET parameterization, actual ET map generation, etc.. Spatial distribution of LST and NDVI shows a contrary direction [12].

In this study, the relationship of actual evapotranspiration with NDVI and LST which are the major evapotranspiration determining factors had been studied. This study was carried out for all seven agro-climatic zones of Tamil Nadu which varies in soil features, precipitation distribution, irrigation pattern, cropping system and other ecological and social features.

2. MATERIAL AND METHODS

2.1 Study Area

This study was carried out for entire Tamil Nadu state of India which extends from 8.50^{o}-13.35^{o} N latitude to 78.35^{o} – 80.20^{o} E longitude with the total geographical area of 1,30,058 km^{2}. Tamil Nadu is divided into seven agro-climatic zones (ACZs) as shown in Fig.1 [**13**]. Average rainfall of Tamil Nadu is 945 mm in which 48 percent contributed by North-East monsoon while 32 percent contributed by South-West monsoon [14]. This study was carried out for south west monsoon from 2011 to 2020.

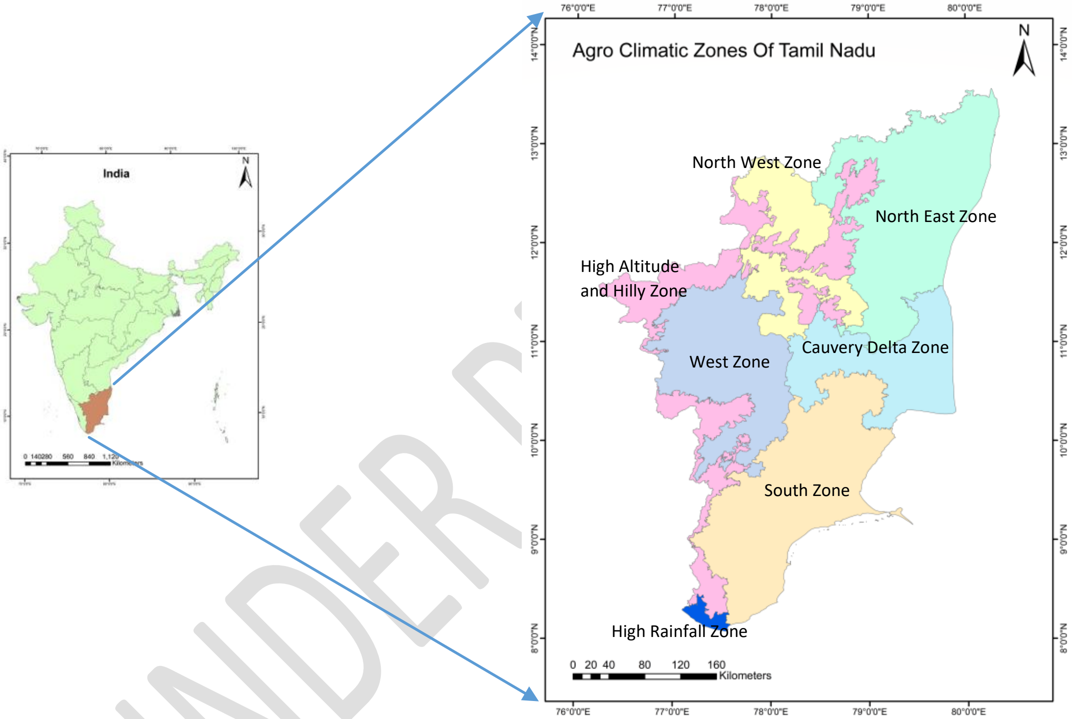


Figure. 1: Study Area Location

Table 1: Agro-Climatic Zones (ACZs) of Tamil Nadu, India

S.No.	ACZs	Districts
1	Cauvery Delta Zone (CDZ)	Ariyalur, Karur, Nagapattinam, Perambalur. Thanjavur, Thiruvarur and Tiruchirapalli
2	High Altitude and Hilly Zone (HAHZ)	The Nilgiris
3	High Rainfall Zone (HRZ)	Kanayakumari
4	North Eastern Zone (NEZ)	Chennai, Cuddalore, Kancheepuram, Thiruvallur, Thiruvannamalai, Vellore and Villupuram

5	North Western Zone (NWZ)	Dharmapuri, Krishnagiri, Namakkal and Salem
6	Southern Zone (SZ)	Dindigul, Madurai, Pudukkottai, Ramanad, Sivagangai, Theni, Tirunelveli, Tuticorin and Virudhunagar
7	Western Zone (WZ)	Coimbatore, Erode and Tiruppur

Table 2: Zonal Description of Tamil Nadu

S.No.	ACZs	Altitude above ground level (AGL)	Rainfall During SWM (mm)	Annual Rainfall (mm)
1	Cauvery Delta Zone (CDZ)	100-200	279.2	984
2	High Altitude and Hilly Zone (HAHZ)	2000	772.8	2124
3	High Rainfall Zone (HRZ)	100-2000	502.3	1420
4	North Eastern Zone (NEZ)	100-200	419.1	1105
5	North Western Zone (NWZ)	200-600	381.5	875
6	Southern Zone (SZ)	100-600	221.2	857
7	Western Zone (WZ)	200-600	220.0	715

2.2 Data

Actual evapotranspiration (AET), Land Surface Temperature (LST) and Normalised Difference Vegetation Index (NDVI) data products were downloaded for MOD16A2.061 [15], MOD11A2.061 [16] and MOD13Q1.061 [17] respectively, from MODIS satellite for 2011-2020 from Land Processes Distributed Active Archive Center (LP DAAC) and it is one of several discipline-specific data centers within the NASA Earth Observing System (EOS) (https://lpdaac.usgs.gov). For SWM season 16 sets of actual ET, LST and 8 sets of NDVI data's were available for each year.

Table 3: MODIS Data Product Details for ET, LST AND NDVI

S.N	Parameter	Sensor	Data Acquisition Interval	Spatial Resolution	Unit	Scale Factor (SF)
1	Actual ET (AET)	MOD16A2	8	500m	$Kg/m^2/8day$	0.1
2	Land Surface Temperature (Day)	MOD11A2	8	1000m	K	0.02
3	NDVI	MOD13Q1	16	500m	-	0.0001

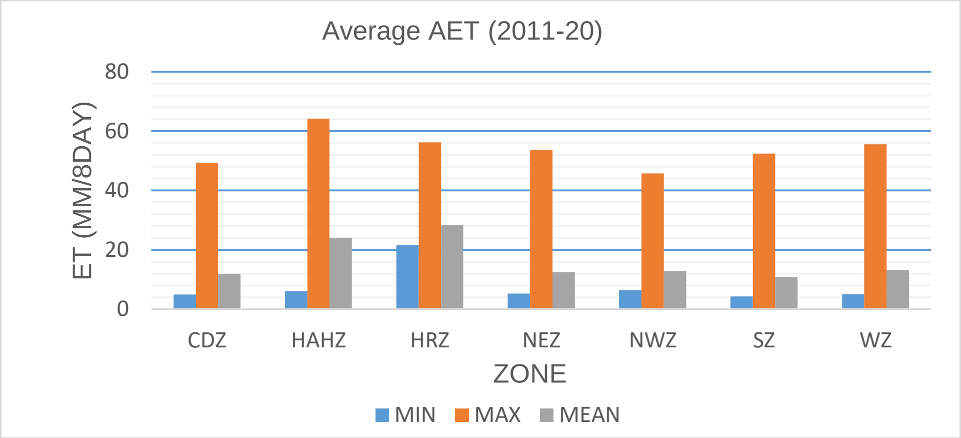


Figure. 2: Average AET (2011-2020) during SWM

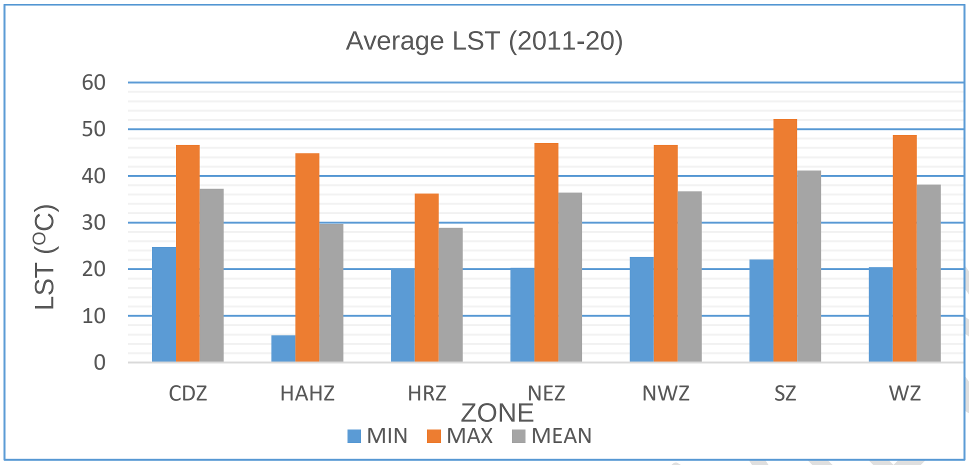


Figure. 3: Average LST (2011-2020) during SWM

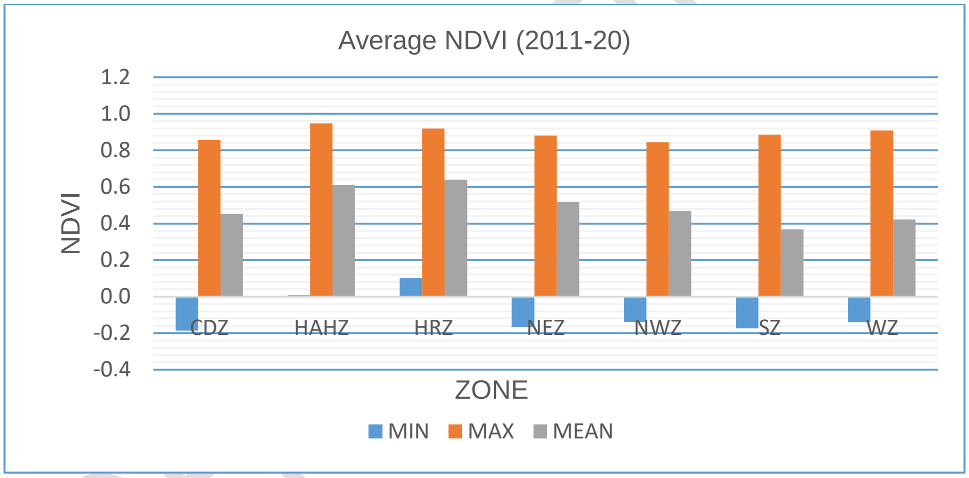


Figure. 4: Average NDVI (2011-2020) during SWM

2.3 Data Processing

Satellite data products were processed and analysed for each zones separately using GIS software. Zonal statistics tools were applied to calculate the maximum, minimum, mean and standard deviation values using the zone shape files of each zones and further analysis were carried out using MS-Excel software. Ten years average map of AET, LST and NDVI imageries were prepared for SWM season using GIS software.

3. RESULTS AND DISCUSSION

3.1. Spatial Contrast in the Distribution of actual ET

The spatial distribution of actual evapotranspiration (AET) for the seven Agro Climatic Zones (ACZs) of Tamil Nadu are represented in Table 4. Among the ACZs of Tamil Nadu, the average AET varied from

10.9 to 28.3 mm/8-day. During the SWM, the mean AET (28.3 mm/8-day) was higher in High Rainfall Zone (HRZ) when compared with all other ACZs. Since the ratio of transpiration to total evaporation depends on vegetation coverage, surface wetness and the availability of soil water for vegetation root transpiration uptake [18] and also recent modeling analysis confirmed the dependence of ET on vegetation [19, 20]. The lower AET was observed in South Zone (SZ) where the rainfall and vegetation cover was sparse with lesser NDVI values (0.4). The variation of AET was found to be higher in High Altitude and Hilly Zone (HAHZ) followed by Western Zone (WZ) with standard deviation values of 8.1 and 5.4 respectively.

Table 4: Spatial variations in the distribution of actual ET (mm/8-day) for SWM season (2011–2020)

Zone	AET (mean)	STD
CDZ	11.8	3.5
HAHZ	24.0	8.1
HRZ	28.3	5.2
NEZ	12.5	3.2
NWZ	12.8	3.0
SZ	10.9	4.8
WZ	13.3	5.4

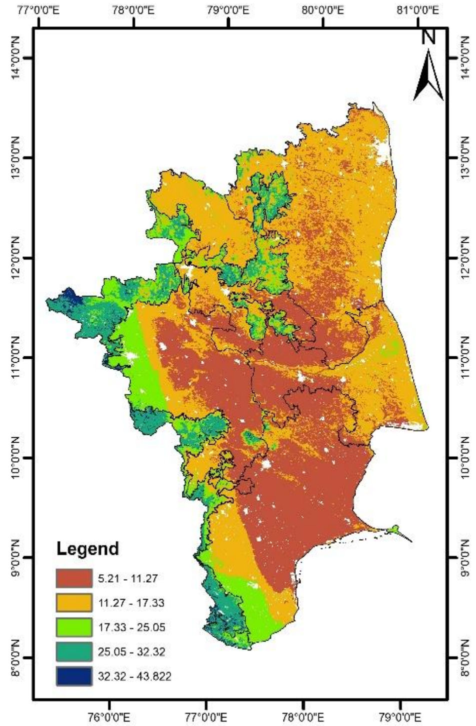


Figure. 5: Spatial Distribution of Actual Evapotranspiration (mm/8-day) during SWM (2011-2020)

3.2. Spatial Contrast in the Distribution of Land Surface Temperature

The spatial distribution of Land Surface Temperature (LST) for the seven ACZs of Tamil Nadu are given in Table 5. Among the ACZs of Tamil Nadu, the mean LST varied from 28.9 to 41.1^{o}C during SWM. Lower mean LST was observed for HRZ which might be due to high rainfall whereas higher mean LST observed for South Zone (SZ) might be due to low rainfall during the SWM season. Lowest LST was observed in HAHZ (>2000m) as elevation and slope are negatively correlated with LST [21] and highest LST was observed in SZ (52.19 ^{o}C) during the study period.

Table 5: Spatial variations in the distribution of LST (^{o}C) for SWM season (2011–2020)

Zone	LST (mean)	STD
CDZ	37.2	3.2
HAHZ	29.7	5.1
HRZ	28.9	2.4
NEZ	36.5	3.1
NWZ	36.7	3.5
SZ	41.2	4.2
WZ	38.1	3.9

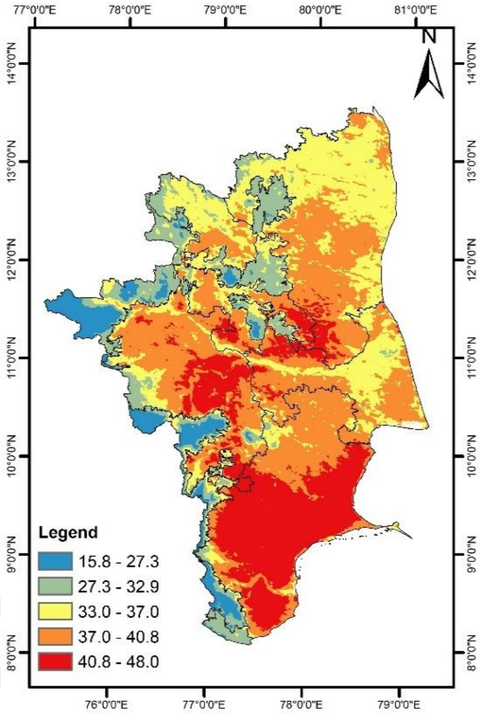


Figure. 6: Spatial distribution of LST (^{0}C) during SWM (2011-2020)

3.3. Spatial distribution of Normalised Difference Vegetation Cover in different zones

Average NDVI values was ranged from 0.4 to 0.6 for the different ACZs of Tamil Nadu. Higher mean NDVI was observed for HRZ and HAHZ (0.6) which might be due to comparatively higher rainfall in these zone. Lower NDVI values were observed in SZ and WZ (0.4) which might be due to low rainfall in these zone [22]. NDVI showed lesser variation its values inside the ACZs.

Table 6: Spatial variations in the distribution of NDVI for SWM season (2011–2020)

Zone	NDVI (mean)	STD
CDZ	0.5	0.1
HAHZ	0.6	0.2
HRZ	0.6	0.1
NEZ	0.5	0.1
NWZ	0.5	0.1

SZ	0.4	0.1
WZ	0.4	0.1

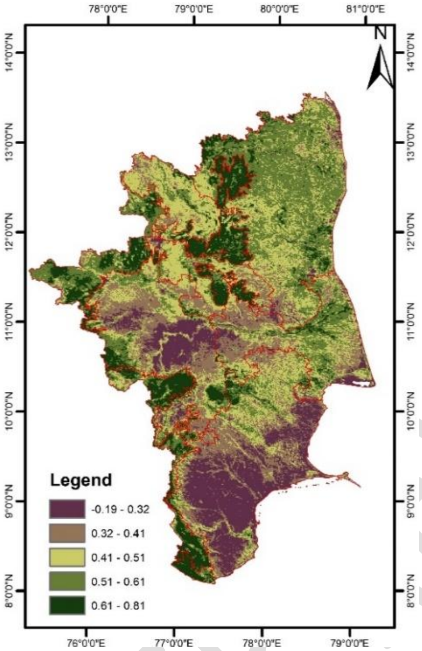


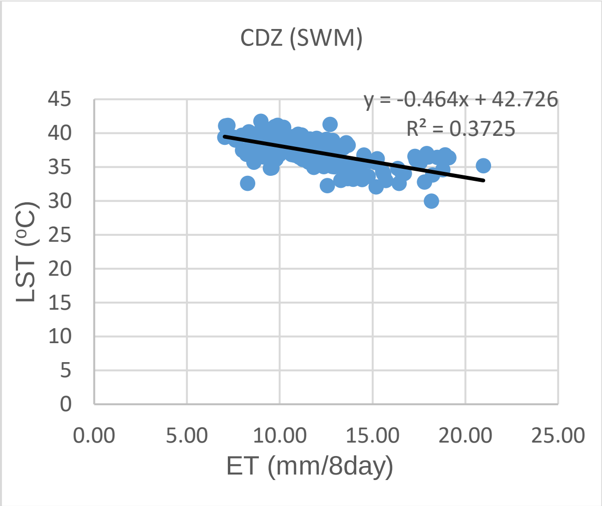
Figure. 7: Spatial Distribution of NDVI during SWM (2011-2020)

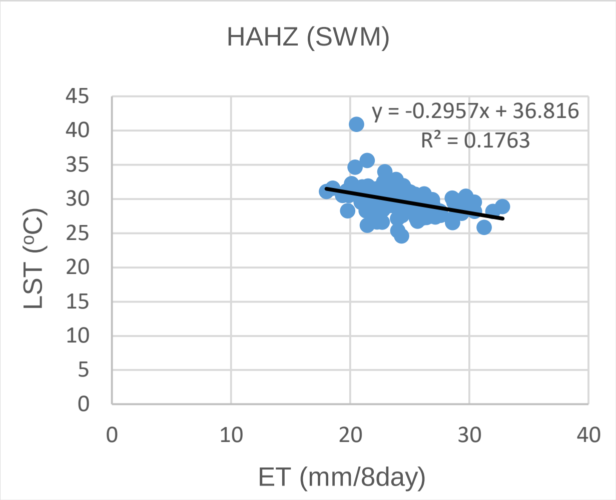
3.4. Relationship between actual ET and Land Surface Temperature

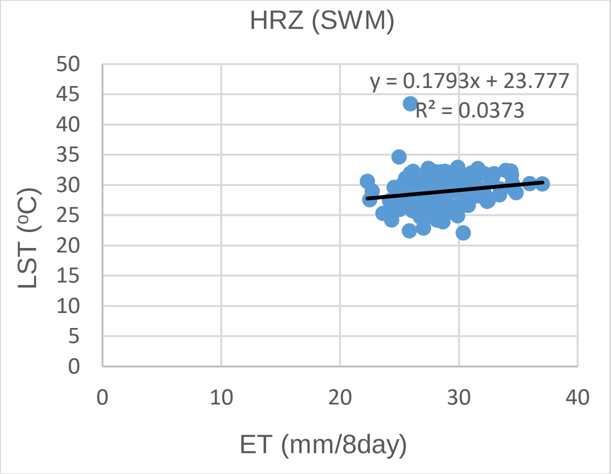
The cooling effect of latent heat and high thermal inertia of wet surfaces together result in low LST [23, 24]. This study indicated that except High Rainfall Zone (HRZ), other zones showed negative correlation between actual ET and LST. ET and LST maintain a negative relationship with changes in air temperature under the water-limited condition [12]. West Zone, High Altitude and Hilly Zone (HAHZ), North West Zone (NWZ) and South Zone (SZ) showed moderate correlation having r values (-0.4, -0.4, -0.6 and -0.5) respectively. Cauvery Delta Zone (CDZ) and North East Zone (NEZ) showed strong correlation (r= -0.6 and -0.7) and HRZ showed very weak positive correlation (r= 0.2) as shown in table below. Positive correlation between actual ET and LST in HRZ might be due to high soil moisture content because of high rainfall during SW monsoon (502.3mm) and high vegetation cover during SW monsoon season (NDVI=0.6).In cold areas, temperature becomes a major control of latent heat is positively related which is representative of actual ET [25,26].

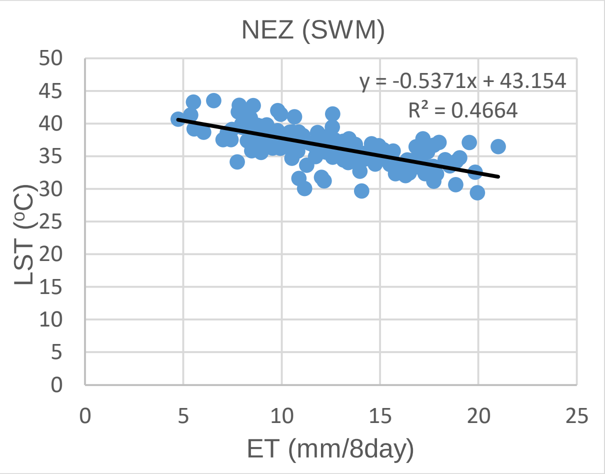
Table 7: Average ET, LST, R^2 and correlation coefficients between ET and LST

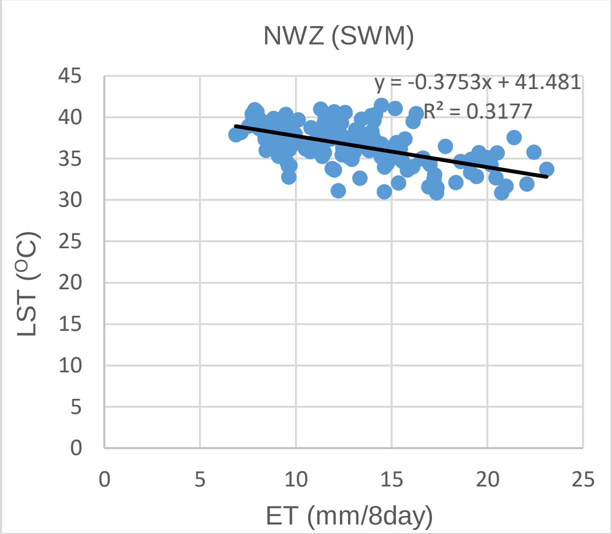
Zone	AET (mean) (mm/8-day)	LST (mean) (^oC)	Correlation Coefficient (r)	R^2
CDZ	11.8	37.2	-0.6	0.4
HAHZ	24.0	29.7	-0.4	0.2
HRZ	28.3	28.9	0.2	0.0
NEZ	12.5	36.5	-0.7	0.5
NWZ	12.8	36.7	-0.6	0.3
SZ	10.9	41.2	-0.5	0.2
WZ	13.3	38.1	-0.4	0.2

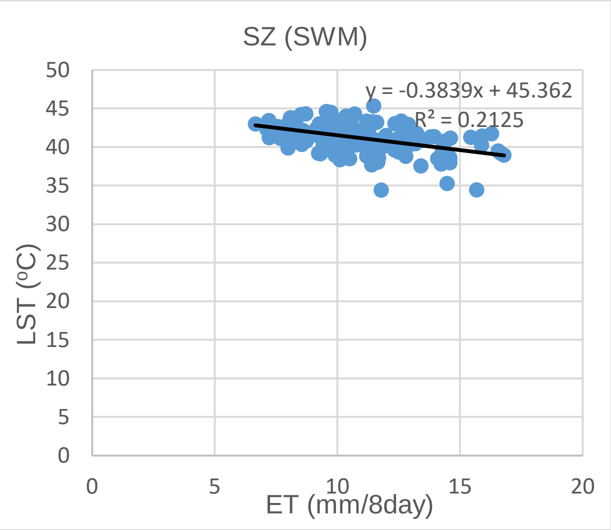

CDZ (SWM)
y = -0.464x + 42.726
R² = 0.3725
LST (ºC)
45
40
35
30
25
20
15
10
5
0
0.00
5.00
10.00
15.00
20.00
25.00
ET (mm/8day)


HAHZ (SWM)
y = -0.2957x + 36.816
R² = 0.1763
LST (ºC)
45
40
35
30
25
20
15
10
5
0
0
10
20
30
40
ET (mm/8day)


HRZ (SWM)
y = 0.1793x + 23.777
R² = 0.0373
LST (ºC)
50
45
40
35
30
25
20
15
10
5
0
0
10
20
30
40
ET (mm/8day)


NEZ (SWM)
y = -0.5371x + 43.154
R² = 0.4664
LST (ºC)
50
45
40
35
30
25
20
15
10
5
0
0
5
10
15
20
25
ET (mm/8day)


NWZ (SWM)
y = -0.3753x + 41.481
R² = 0.3177
LST (ºC)
45
40
35
30
25
20
15
10
5
0
0
5
10
15
20
25
ET (mm/8day)


SZ (SWM)
y = -0.3839x + 45.362
R² = 0.2125
LST (ºC)
50
45
40
35
30
25
20
15
10
5
0
0
5
10
15
20
ET (mm/8day)

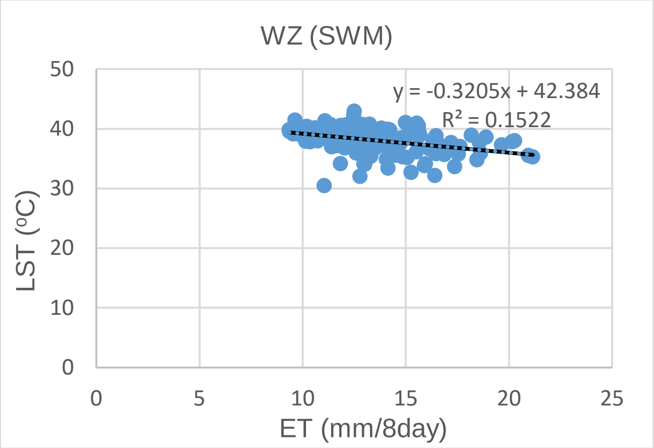


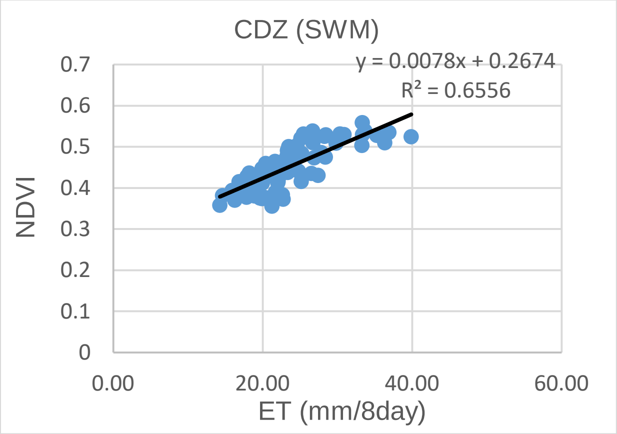
Figure. 8: AET and LST Regression equations for different ACZs of Tamil Nadu during SWM season.

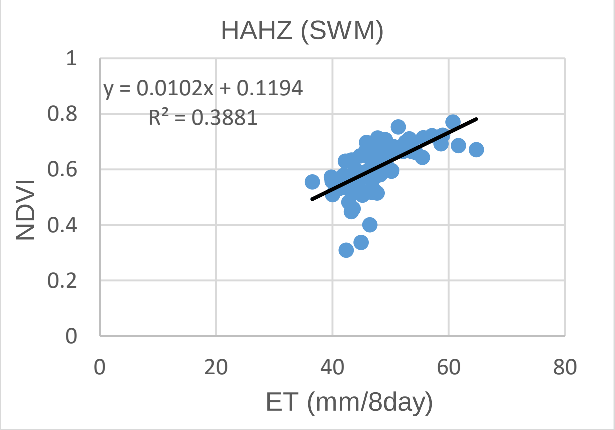
3.5. Relationship between actual ET and Normalised Difference Vegetation Index

Actual ET showed weak to strong positive correlations with the most commonly used vegetation index (NDVI). ET and NDVI showed weak correlation (r=0.3) in High Rainfall Zone (HRZ), moderate correlation (r=0.6) in Western Zone (WZ), strong positive correlation coefficient of 0.6, 0.7 and 0.7 in High Altitude and Hilly Zone (HAHZ), North West Zone (MWZ) and South Zone (SZ) respectively and very strong correlation coefficient of 0.8 and 0.9 in Cauvery Delta Zone (CDZ) and North East Zone (NEZ) respectively. On an average, ratio of plant transpiration to total evaporation increases with vegetation coverage [27].

Table 8: Average ET, NDVI, R^2 and correlation coefficients between ET and NDVI

Zone	AET (mean) (mm/8-day)	NDVI (mean)	Correlation Coefficient (r)	R^2
CDZ	11.8	0.5	0.8	0.7
HAHZ	24.0	0.6	0.6	0.4
HRZ	28.3	0.6	0.3	0.1
NEZ	12.5	0.5	0.9	0.7
NWZ	12.8	0.5	0.7	0.5
SZ	10.9	0.4	0.7	0.5
WZ	13.3	0.4	0.6	0.3





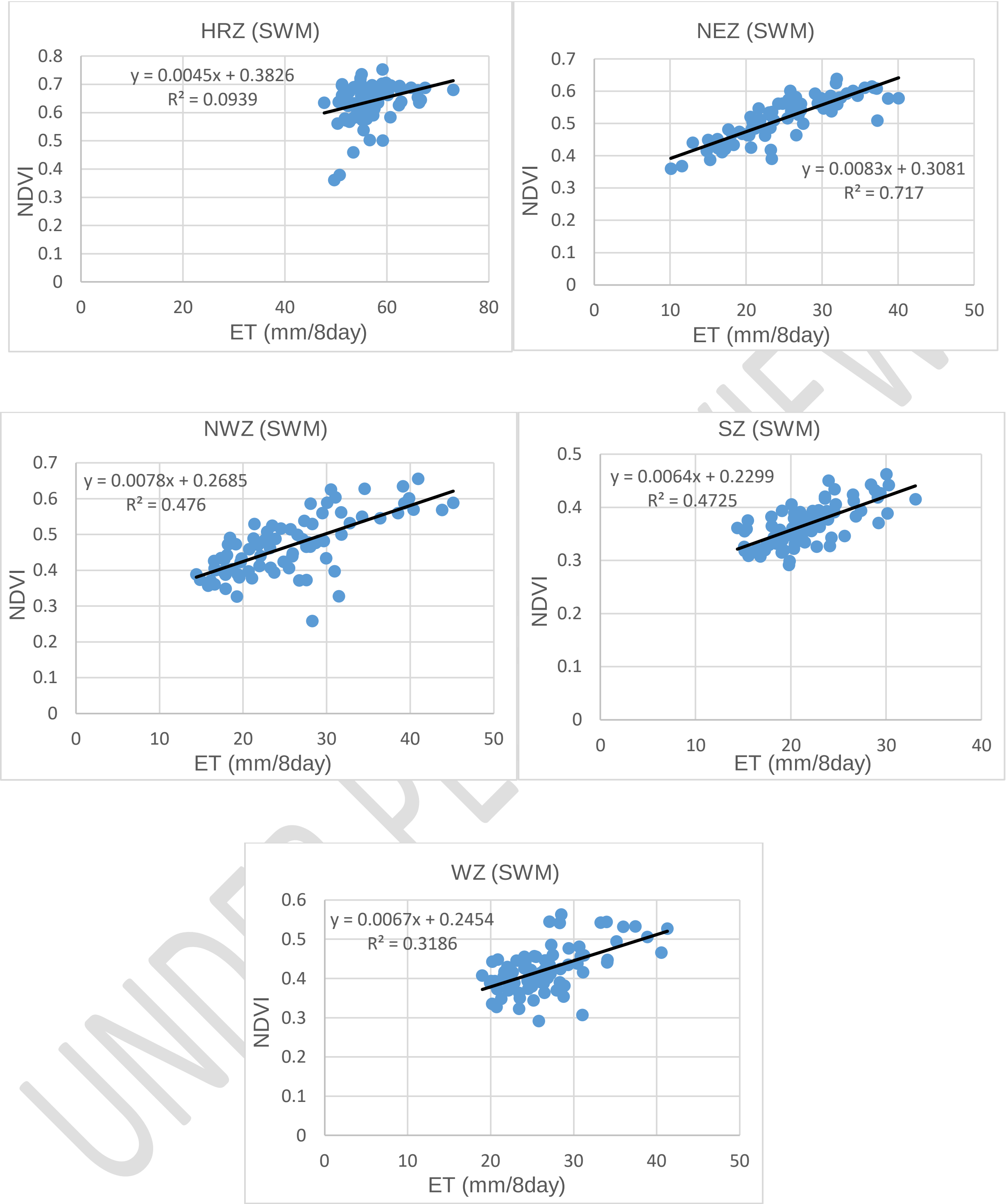


Figure.9: AET and NDVI Regression equations for different zones of Tamil Nadu during SWM season.

4. CONCLUSION

Actual ET is the combined process of evaporation and transpiration which shows high fluctuation with meteorological factor as well as vegetative characteristics. AET and LST showed negative correlation but it also showed a weak positive correlation in High Rainfall Zone (r=0.2) where high rainfall was observed during SWM. ET and NDVI always possessed positive correlation in all agro-climatic zones of Tamil Nadu during south west monsoon season. High Altitude and Hilly Zone showed maximum variation in actual ET, LST and NDVI data products.

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